GALLIUM NITRIDE BASED COMPOUND SEMICONDUCTOR LIGHT-EMITTING DEVICE AND MANUCFACTURING METHOD THEREFOR

BACKGROUND OF THE INVENTION

1.Field of the invention

The present invention relates to a GaN based compound semiconductor light-emitting device (LED) and a manufacturing method therefor, and particularly to a GaN based compound semiconductor light-emitting device (LED) with better light transparency and a manufacturing method therefor.

2.Description of Related Art

A light-emitting diode (LED) has been generally known as a semiconductor device with ability to emitting light, which has been widely used in digital watches, calculators, communications and other areas, such as mobile phone and some appliances. Recently, various efforts and attempts have shifted to use LEDs in more ordinary human living, such as large panels, traffic lights and illumination facilities. However, in marching into a brand new illuminating era with the current illumination facilities replaced with LEDs, the luminous efficiency of an LED remains a big issue, which has been challenging those skilled in the art for many years. Therefore, many developments and researches have been thrown in to improvement of luminous efficiency of

LEDs, and red, green, blue and white colored lights are alike.

As is well understood to those skilled in the art, LEDs are produced based on some semiconductor materials, especially GaN-based compound semiconductor materials, and emit lights by virtue of the behaviors aroused in the semiconductor materials in the presence of an applied electrical bias.

In particular, an LED is generally composed of some Group III-V (or Group II-VI, although rarely given forth) compound semiconductors. In principle, an LED is basically a well-known p-n junction structured device, i.e., a device having a p region, an n region and a depletion region therebetween. Upon a forward-biased voltage or current bias applied, the majority of the carriers in the p or n regions drift respectively towards the other region through the depletion region in the device due to the energy equilibrium principle and a current is accounted for, in addition to the general thermal effects. When some electrons and holes in the device jumped into a higher value of energy band with the aid of electrical and thermal energy, the electrons and the holes recombine there and then give off lights when they randomly fall back to a previous lower energy state (turning from an unsteady state to a steady state) owing to thermal equilibrium principle, i.e. spontaneous emission. Besides the p-n junction, in a typical and basic such device structure comprise also other components, such as a substrate, a buffer layer, a transparent layer (TCL) and electrodes. In achieving a high luminous efficiency LED, each component and their mutual relationship in the device structure are generally to be considered.

In a typical LED in which the produced light is emitted upward (through the overlaying epitaxy structure), TCL is a layer coated on an LED structure and below a p-type electrode of the LED structure. Since the p-type electrode is normally not transparent or not transparent enough and will have blockage on the emitted light to a user's eyes, the p-type electrode should be sized and disposed at a limited portion on the underlying layer contact therewith. However, the electrical force lines resulted from between the p-type electrode and an n-type electrode may not uniformly distribute in the p-n structure in the device. Hence, the electrical charges provided by the applied electrical bias may not efficiently and uniformly stimulate the p-n structure, which is the source of light generation. Further, the p-type electrode is inhered with poor mobility as compared to that of the n-type electrode and thus the stimulation efficiency of the electric bias on the device may not be satisfactory. A thin TCL is in this occasion introduced over the toppest layer of the device (in fact, below the p-type electrode). The TCL is a transparent material to a light generated from the device and equipped with ability of electricity conduction. Once an electric bias is fed from the p-type electrode, the corresponding charges will spread uniformly in the p-n structure with an aid of the TCL underlying the p-type electrode and the poor stimulation efficiency of the electric bias may be overcome. In this regard, a TCL is a layer indispensable to an LED structure.

In a prior art, a Ni/Au material (with the Ni layer at the lower and the Au

layer thereon) is used as the TCL in the GaN based light-emitting device in achieving an improved light emitting device. However, Ni/Au is not a material with good light transparency and should thus be made considerably thin, about 0.005-0.2 μm. On the other hand, according to the critical angle theory, TCL should possess suitable thickness and will then facilitate extraction of the generated light out of the device. Further, too thin a Ni/Au layer will not exhibit a good ohmic contact characteristic. Therefore, Ni/Au material may not be the most appropriate choice for an LED in terms of light transparency and extraction owing to the thickness issue. Further, since Ni/Au as the TCL in such a GaN based light emitting device may not be formed with more facets by use of a surface treatment under the thickness 0.005-0.2 μm of the Ni/Au layer, the Ni/Au layer based light extraction stands little possibility to be promoted.

In view of the foregoing problems, it is needed to set forth a GaN based compound semiconductor LED that really provides an improved TCL. To this end, the inventors of the present invention provide herein a GaN based compound semiconductor LED with a TCL other than Ni/Au and may achieve better light transparency and extraction characteristics.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a GaN based compound semiconductor light emitting device (LED) which has a better transparent contact layer (TCL), may be made bulky and facet-rich, and thus

has a higher light extraction characteristic, and a corresponding manufacturing method.

To achieve the object of the present invention, an impurity doped metal oxide is used as the TCL of the LED, instead of Ni/Au material used in the state of the art. In a preferred embodiment, the impurity doped metal oxide may be an impurity doped ZnO based layer. When the doped ZnO based layer is thick enough, the surface thereof may be subject to a surface treatment so that facets thereon may be made more.

With the inventive GaN based compound semiconductor LED having an impurity doped metal oxide as the TCL and its manufacturing method, the obtained light extraction efficiency is enhanced.

In the inventive LED structure, the constituent materials comprise: a substrate, a multi-layer epitaxial structure, a light extraction layer, an n-type electrode and a p-type electrode. In the multi-layer epitaxial structure, there include a buffer layer, a first semiconductor layer, a light generating layer and a second semiconductor layer.

A manufacturing method for the inventive LED comprises: (a) forming an n-GaN based layer over a substrate; (b) forming a multi-quantum well (MQW) active layer over the n-GaN based layer; (c) forming a p-GaN based layer over the MQW layer and etching away a portion of the n-GaN layer,

MQW active layer and p-GaN layer, whereby an exposing region is formed on the n-GaN layer; (d) forming an impurity doped metal oxide layer as a light extraction layer over the p-GaN based layer; and (e) forming an n-type electrode over an exposing region after the etching of the n-GaN based layer, the MQW active layer and the p-GaN layer and forming a p-type electrode over the light extraction layer. In a preferred embodiment, the doped metal oxide layer is an Al-doped ZnO-based layer.

Owing to the large bandgaps of some metal oxides such as ZnO, the LED with a TCL composed of such metal oxides exhibiting better light transparency and extraction is thus achieved.

Additionally, the LED according to the present invention also includes at least the following advantages: bulky light extraction layer and the corresponding light extraction efficiency, surface treated light extraction layer with more facets and the corresponding light extraction.

BRIEF DESCRIPTION OF THE DRAWINGS

To better understand the other features, technical concepts and objects of the present invention, one may clearly read the description of the following preferred embodiment and the accompanying drawings, in which:

Fig. 1 depicts schematically a manufacturing method of a preferred embodiment according to the present invention;

Fig. 2 is a schematically perspective diagram of a light-emitting device of a preferred embodiment according to the present invention;

Fig. 3 depicts schematically a structure of a light-emitting device of a preferred embodiment according to the present invention;

Fig. 4 depicts schematically energy the bandgaps of a ZnO and a p-GaN materials;

Fig. 5 depicts schematically light extraction of a light-emitting device;

Fig. 6 depicts schematically a manufacturing method of another embodiment according to the present invention;

Fig. 7 and Fig. 8 depict schematically a surface treatment of a light extraction layer;

Fig. 9 depicts schematically light extraction from particularly textured area;

Fig. 10 and Fig. 11 depict schematically a particularly textured area of another embodiment according to the present invention;

Fig. 12 depicts schematically a method of a second embodiment according to the present invention;

Fig. 13 depicts schematically a device of a second embodiment according to the present invention;

Fig. 14 depicts schematically another example of a second method embodiment according to the present invention;

Fig. 15 depicts schematically a method of a third embodiment according to the present invention;

Fig. 16 depicts schematically a device of a third embodiment according to

the present invention;

Fig. 17 depicts schematically another example of a third method embodiment according to the present invention;

Fig. 18 depicts schematically a method of a fourth embodiment according to the present invention;

Fig. 19 depicts schematically a device of a fourth embodiment according to the present invention; and

Fig. 20 depicts schematically anther example of a fourth method embodiment according to the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In a preferred (first) embodiment of an LED of the present invention schematically shown in Fig. 1 through 3, the LED is included with an impurity doped ZnO based layer at the toppest thereof (but under a p-type electrode in the LED). The doped ZnO based layer is formed over a multi-layer epitaxial structure and has a better light transmissibility and a suitable thickness, entitling itself to better light extraction for the LED. Specifically, the method and the LED structure are described in Fig. 1 and 2 respectively and each step thereof will be first explained as follows accompanying with its element labels.

Step 1: forming an n-GaN based epitaxial layer 21 over a substrate 10. The substrate 10 may be a sapphire or SiC and have a thickness of 300-450 μm, The substrate 10 may be first formed with a buffer layer 22 at an upper surface

11 thereof, and then formed over with the n-GaN based epitaxial layer 21 having a thickness of 2-6 μm. The buffer layer may be composed of some layers, such as a coarse grain nucleation layer made of GaN and an undoped GaN layer. The nucleation layer is a low temperature layer, i.e. formed under a low temperature condition, and has a thickness of 30-500 Å and will be referred to as an LT-GaN layer herein. The undoped GaN is a high temperature layer and has a thickness of 0.5-6 μm, and will be named as an HT-GaN layer here. These buffer layers may be formed by molecular beam epitaxy (MBE), metal organic chemical vapor deposition (MOCVD) and some other suitable technologies, currently in existence or set forth in the future.

Step 2: forming a multi-quantum well (MQW) active layer 23 over the n-GaN based layer 21. As generally known, an MQW layer is a multi-layered structure and used to enhance possibility of recombination of holes and electrons in the p-and-n junction structure of the LED. In the present invention, the thickness and layer number of the MQW layer may be carefully chosen so that the MQW layer may efficiently increase light generating efficiency. In addition, the active layer 23 may be served by an AlGaInN based compound semiconductor epitaxial layer.

Step 3: forming a p-GaN based epitaxial layer 25 over the MQW active layer 23 and etching away a portion of the n-GaN based layer 21, the MQW active layer 23 and the p-GaN based layer 25 whereby an exposing region 21a is formed on the n-GaN based layer 21, wherein the p-GaN based epitaxial layer 25 may be such as p-GaN, p-InGaN and p-AlInGaN layers and have a

thickness of 0.2-0.5 μm. It is noted that the etching may be performed with chlorine plasma dry etching, etc.

Step 4: forming a doped ZnO based layer 31 over the remaining p-GaN based layer 25 after said etching. Since the layer 31 is provided at the toppest of the LED structure for light exiting excepted for a p-electrode 50, the layer is also termed as a window layer. The thickness of this doped ZnO based layer may be arranged between 50Å and 50 μm. Preferably, the thickness is made larger than 1 μm, and the reason will be stated in the following related to the LED structure. In a prefer embodiment, the impurity doped in the doped ZnO based layer 31 may be a p-type impurity or an n-type impurity, and the p-type impurity may at least be Al. Once the activation issue of the impurity doped ZnO based layer 31 may be overcome, all Group-III elements may be the suitable dopants.

Step 5: forming a p-type electrode 50 over the doped ZnO based layer 31 and forming an n-type electrode 40 over said exposing region 21a of said n-GaN based layer 21.

As far as formation of the doped metal oxide layer ZnO is concerned, either of self-texturing by sputtering, physical vapor deposition, ion plating, pulsed laser evaporation chemical vapor deposition and molecular beam epitaxy and other suitable technologies may be employed.

In fact, to completely form a marketed LED, some treatments are also needed comprising wire bonding and packaging molded by such as epoxy (not shown). Since the wire bonding and packaging technology is well known to those persons skilled in the art, they are omitted in the detailed descriptions, for simplicity, of the inventive LED for both its structure and method.

The following is dedicated to the inventive LED structure. Referring to Fig. 3, the LED structure 12, corresponding to the above manufacturing method, includes a substrate 10, a multi-layer epitaxial structure 20,a first semiconductor layer 24, a light generating layer 26 and a second semiconductor layer 28.

Specifically, said substrate 10 is made of sapphire or SiC and has a thickness of 300-450 μm. The buffer layer 22 is a multi-layer structure such as a double layered one. In this case, the buffer layer 22 is composed of an LT-GaN layer and an HT-GaN layer, as has been explained in the preferred method embodiment, formed over an upper surface 11 of the substrate 10.

The first semiconductor layer 24 is an n-GaN based III-V group compound semiconductor, which may range from 2 to 6 μm in thickness. The light generating layer 26 is an GaN based III-V group compound semiconductor, generally known as an active layer, and may be a GaN multi quantum well (MQW) or an InGaN multi-quantum well. The second semiconductor layer 28 is a p-type GaN based III-V group compound

semiconductor, which may be such as p-GaN, p-InGaN and p-AlInGaN.

The light extraction layer 30 is made of an impurity doped metal oxide, which is light transmissive and formed over the second semiconductor layer 28. As an example and a preferred embodiment, the light extraction layer 30 is composed of doped ZnO. The n-type electrode 40 is disposed over an exposing region 24a of the first semiconductor layer 24 and the p-type 50 over the light extraction layer 30.

With the improved doped ZnO light extraction layer 30, the light generated from the active layer 26 in the inventive LED is more penetratable through when it encounters the layer 30 in the course of going out of the LED. Further, because the light extraction layer 30 may be subject to surface treatment to have the surface roughened and some form textured, the surface of the light extraction layer may obtain more facets and thus the light extracted to a user's eyes may be increased.

Here, there are some descriptions supplemented to the above embodiment. The light generating layer 26, i.e., active layer, may alternatively be a single AlGaInN III-V group compound semiconductor layer. The light extraction layer 30 may further be other metal oxides with impurity doped, such as impurity doped $In_xZn_{1-x}O$, impurity doped $Sn_xZn_{1-x}O$ and $In_xSn_yZn_{1-x-y}O$, one having an index of refraction of at least 1.5, one being n-type conductive or p-type conductive, one doped with a rare earth element, or

one having a transmissive range of a light with a wavelength of 400-700nm.

The afro-mentioned is the preferred embodiment of the present invention, which may be easily modified by those persons skilled in the art. Hence, devices or methods deduced with reference to the disclosed one are deemed to fall within the spirit of the present invention. For example, although the description of the LED and its manufacturing method of the present invention are limited to the Group III-V compound semiconductor based LED, the inventive impurity doped metal oxide light extraction layer may be employed onto the Group II-VI group compound semiconductor based LED as long as the lattice matching issue on such LED may not be problematic.

The following will be made to the reason that doped ZnO may be more appropriate to serve as the light extraction layer as compared to the prior light extraction layer in an LED. Referring to Fig. 4, the bandgap energy B1 of ZnO is approximately 3.4 eV, and the bandgap B2 of p-GaN is also near 3.4 eV. Owing to the small bandgap energy offset, lattice matching will not be an issue to their bonding and the operating voltage will not be too large. In this regard, bonding the impurity doped ZnO extraction layer over the p-GaN layer is well possible. For numerical information, GaN has a lattice constant of about 3.189Å, ZnO of about 3.24Å, and sapphire of about 4.758 Å.

In an LED device, as generally known, only those lights with emitting angles smaller than the critical angle may really extract out of the device,

schematically shown in Fig. 5. In response to this, a light extraction layer with a suitable thickness may be benefited with increased light extraction amount. As the example of the present invention, the light extraction layer 30 has a thickness of at least 1 μ m, which makes the lights emitted from the active layer easier to penetrate through the surface 301 and the sides 302 and thus enhance the light extraction efficiency.

Referring to Fig. 6, since the light extraction layer 30 in the present invention may be ranged between about 50Å-50 μ m in thickness, the layer 30 may be made thick enough to be bulky one. When the thickness of the light extraction layer 30 is at least 1 μ m, the above method embodiment may further include a step, Step 6, i.e., subjecting an exposing surface of the doped ZnO based layer 30 (i.e., the portion of the light extraction layer 30 other than the portion thereof contacted with the p-type electrode 50) to a surface treatment. With the surface treatment, the surface of the layer 30 may be further roughened so that more facets may be formed thereover. With the facet-rich surface, light extraction efficiency may be considerably increased.

Proceeding to the above paragraph, the light extraction layer 30 may be further subject to particular texturization and obtained with textured surface. Similar to the recitation of the above paragraph, texturization treatment may also increase facet number of the light extraction layer 30. And the goal to increasing light extraction may be achieved. The particular textured surface may be in the form of a cone, comprising one with a triangular 303 bottom

shown in Fig. 7 and one with a rectangular bottom 305 shown in Fig. 8, and may be other geometrical cones, which may either be applied onto the light extraction layer 30.

Referring to Fig. 9, that light extraction may be benefited from the roughened or textured surface of the light extraction layer 30 is schematically explained therein. For a flat light extraction layer, a portion of the emitted light is reflected by the flat surface. However, the two facets 302 may provide the emitted light with several times of reflection and the extracted portion of the emitted light may well be increased.

Fig. 10 and 11 are planar diagram and partial perspective diagram respectively for illustration of another textured surface embodiment. In the two figures, the textured portion of the surface may further include a plurality of recesses 307, which may be triangular, rectangular, diamond, polygonal or other arrangements. Between recesses 307 is a distance of a suitable value, which is provided for conductive path of current.

Referring to Fig. 12 and 13, which illustrate a second embodiment of the present invention. In the embodiment, an impurity doped $In_xZn_{1-x}O$ is used as the light extraction layer 32, which is grown to a suitable thickness over the multi-layer structure as mentioned in the first embodiment, wherein $0 \leqq X \leqq 1$. The steps used in this embodiment are generally similar to those in the preferred embodiment except for the step, Step 4a. Step 4a is a step of forming

an impurity doped $In_xZ_{1-x}O$ based layer over the p-GaN layer.

Referring to Fig. 14, the second embodiment according to the present invention may further comprise a step, Step 5a, as compared to that in Fig. 12: subjecting the doped $In_xZ_{1-x}O$ based layer to a surface treatment. In the step, the treatment is applied only to the region of the layer 32 not covered by the p-type electrode 50. Similarly, the increase of facets on the layer 32 may efficiently enhance light extraction.

Referring to Fig. 15 and 16, which illustrate a third embodiment of the present invention. In the embodiment, an impurity doped $Sn_xZn_{1-x}O$ 33 is used as the light extraction layer, which is grown to a suitable thickness over the multi-layer structure as mentioned in the first embodiment, wherein $0 \leqq X \leqq 1$. The steps used in this embodiment are generally similar to those in the preferred embodiment except for the step, Step 4b. Step 4b is a step of forming an impurity doped $Sn_xZn_{1-x}O$ based layer over the etched p-GaN layer.

Referring to Fig. 17, the third embodiment according to the present invention may further comprise a step, Step 5b: subjecting the impurity doped $Sn_xZn_{1-x}O$ based layer to a surface treatment. In this step, the treatment is applied only to the region of the layer 33 not covered by the p-type electrode 50. Similarly, the increase of facets on the layer 33 may efficiently enhance light extraction.

Referring to Fig. 18 and 19, which illustrate a fourth embodiment of the present invention. In the embodiment, an impurity doped $In_xSn_yZn_{1-x-y}O$ is used as the light extraction layer 34, which is grown to a suitable thickness over a multi-layer structure as mentioned in the first embodiment, wherein $0 \leqq X \leqq 1$, $0 \leqq Y \leqq 1$ and $0 \leqq X+Y \leqq 1$. The steps used in this embodiment are generally similar to those in the preferred embodiment except for a step, Step 4c. Step 4c is a step of forming an impurity doped $In_xSn_yZn_{1-x-y}O$ based layer over the etched p-GaN layer 25.

Referring to Fig. 20, the fourth embodiment according to the present invention may further comprise a step, Step 5c: subjecting the impurity doped $In_xSn_yZn_{1-x-y}O$ based layer to a surface treatment. In this step, the treatment is applied only to the region of the layer 34 not covered by the p-type electrode 50. Similarly, the increase of facets on the layer 34 may efficiently enhance light extraction. If the exposing surface of the above mentioned structure is thin enough, the exposing surface can dope no Zno as well.

While the invention has been described by way of examples and in terms of preferred embodiments, it is to be understood that the invention is not limited thereto. On the contrary, it is intended to cover various modifications and similar arrangements and procedures, and the scope of the appended claims therefore should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements and procedures.